OPERATION AND PERFORMANCE OF THE ATLAS L1CALO AND L1TOPO TRIGGERS IN RUN 2 AT THE LHC

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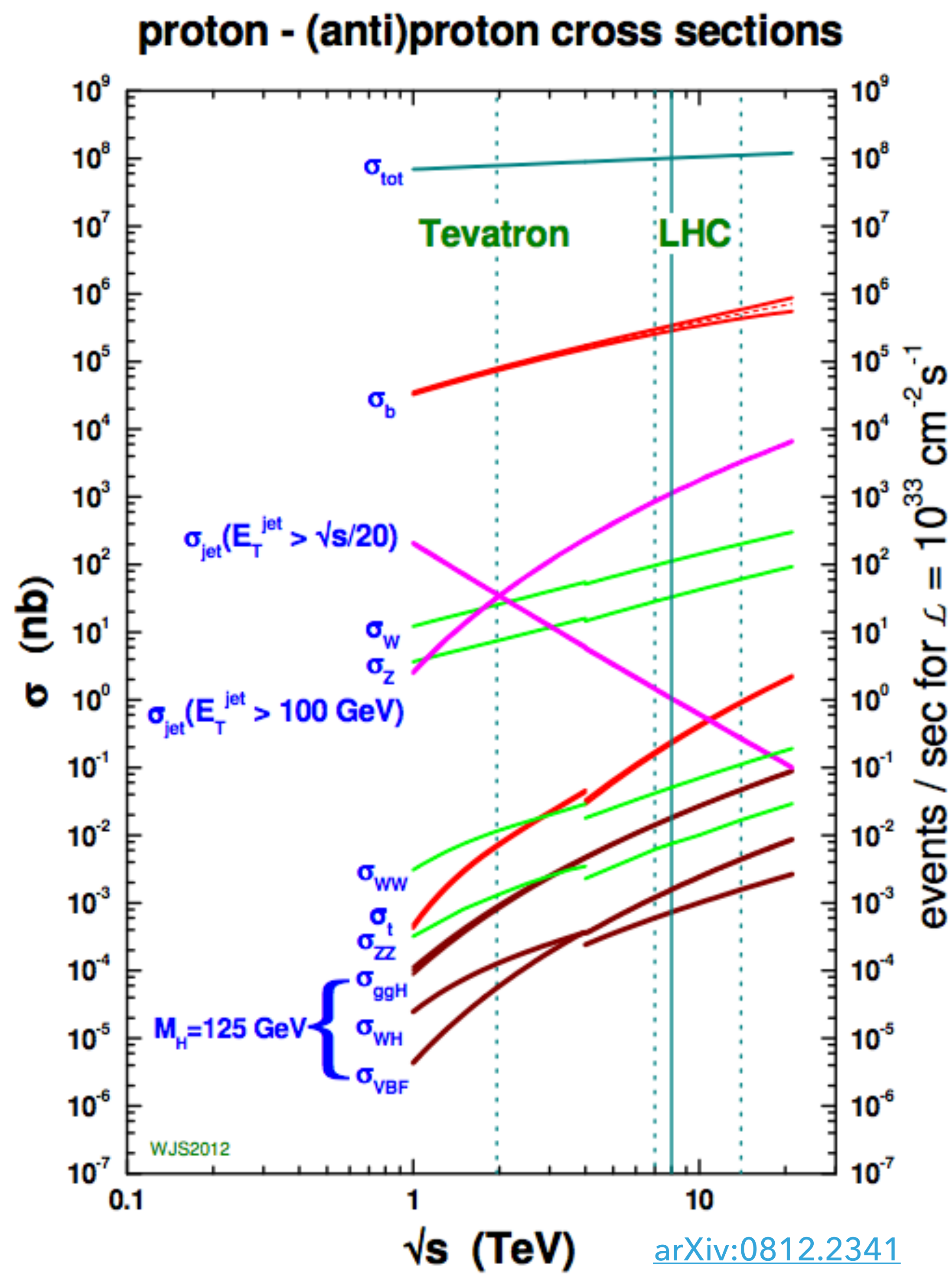
DPF 2017

TRIGGERING AT HADRON COLLIDERS

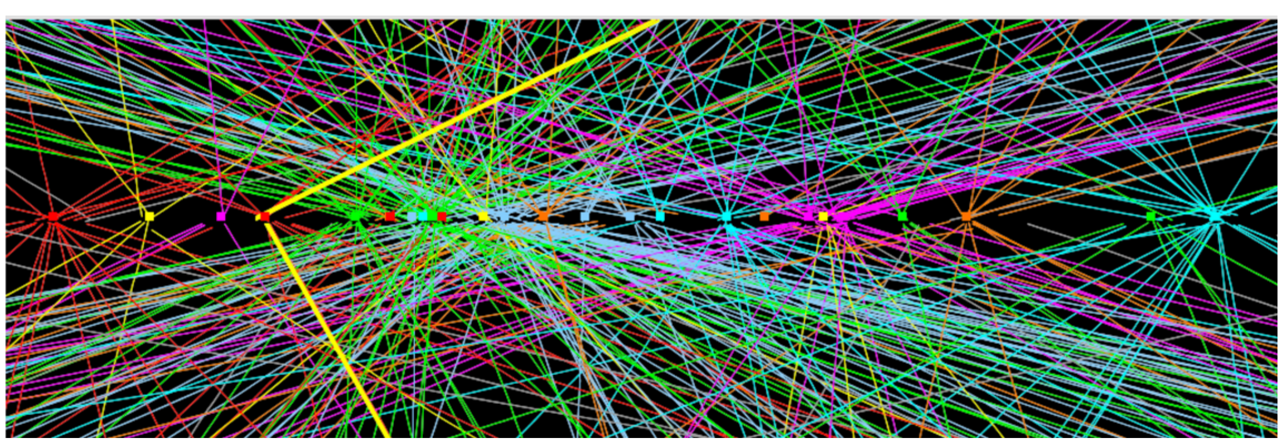
- LHC pp collision rate is ~1 GHz
  - 40 MHz bunch crossing rate
  - ~25 interactions per bunch crossing in 2016
- Interesting physics is produced at a rate 6-8 orders of magnitude lower… or even less often!
- We need triggers to select interesting events to record and analyze offline



arXiv:0812.2341

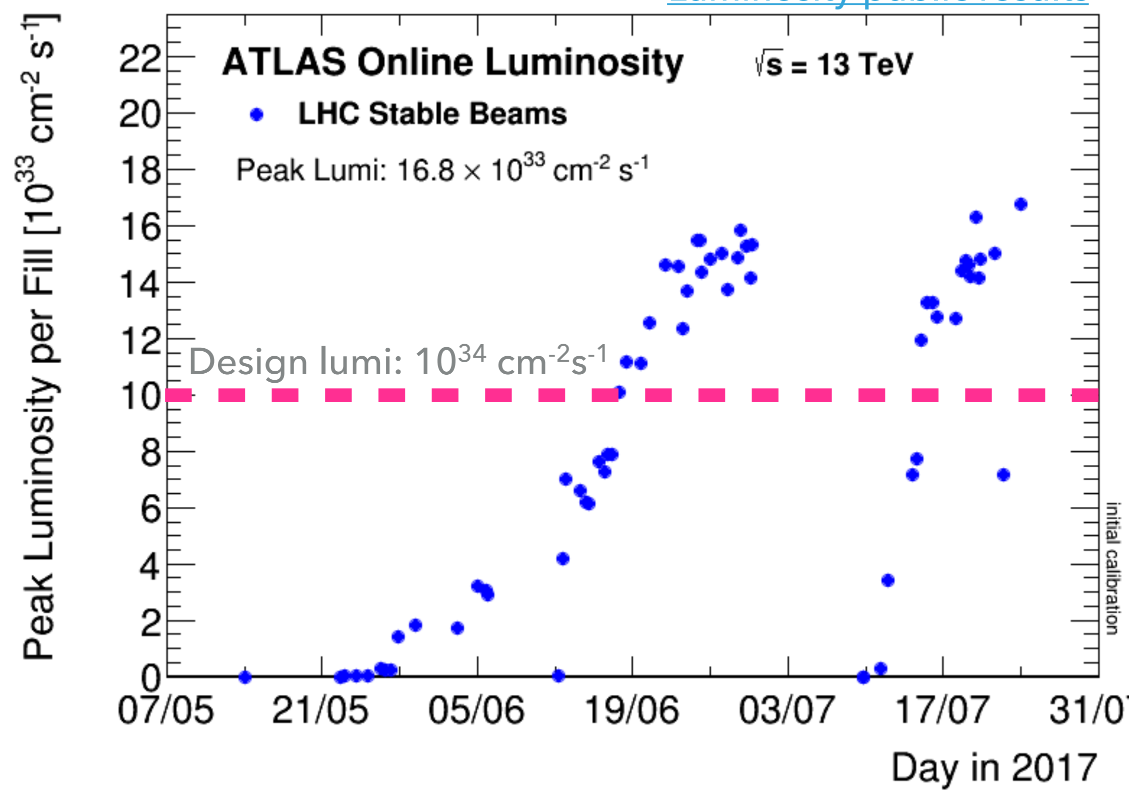
TRIGGERING AT HIGH LUMINOSITY

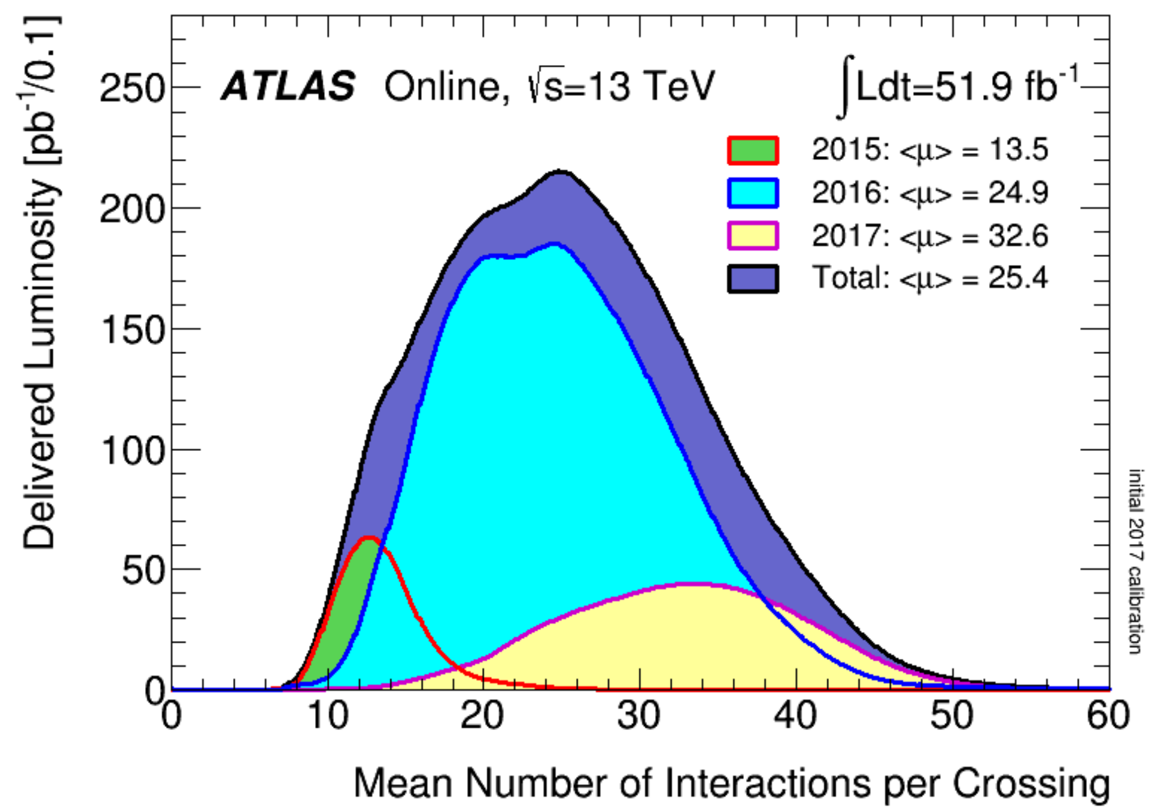
- The LHC has surpassed its design luminosity!
- Average of ~32 interactions per bunch crossing in 2017
  - 40-50 at start of fill
- Pile-up leads to increased trigger rates
  - In-time pile-up: multiple interactions per bunch crossing
  - Out-of-time pile-up: overlapping signals from adjacent bunch crossings
- Need to employ strategies to mitigate pileup effects without raising trigger thresholds



Z→μμ event with 25 reconstructed vertices

Luminosity public results

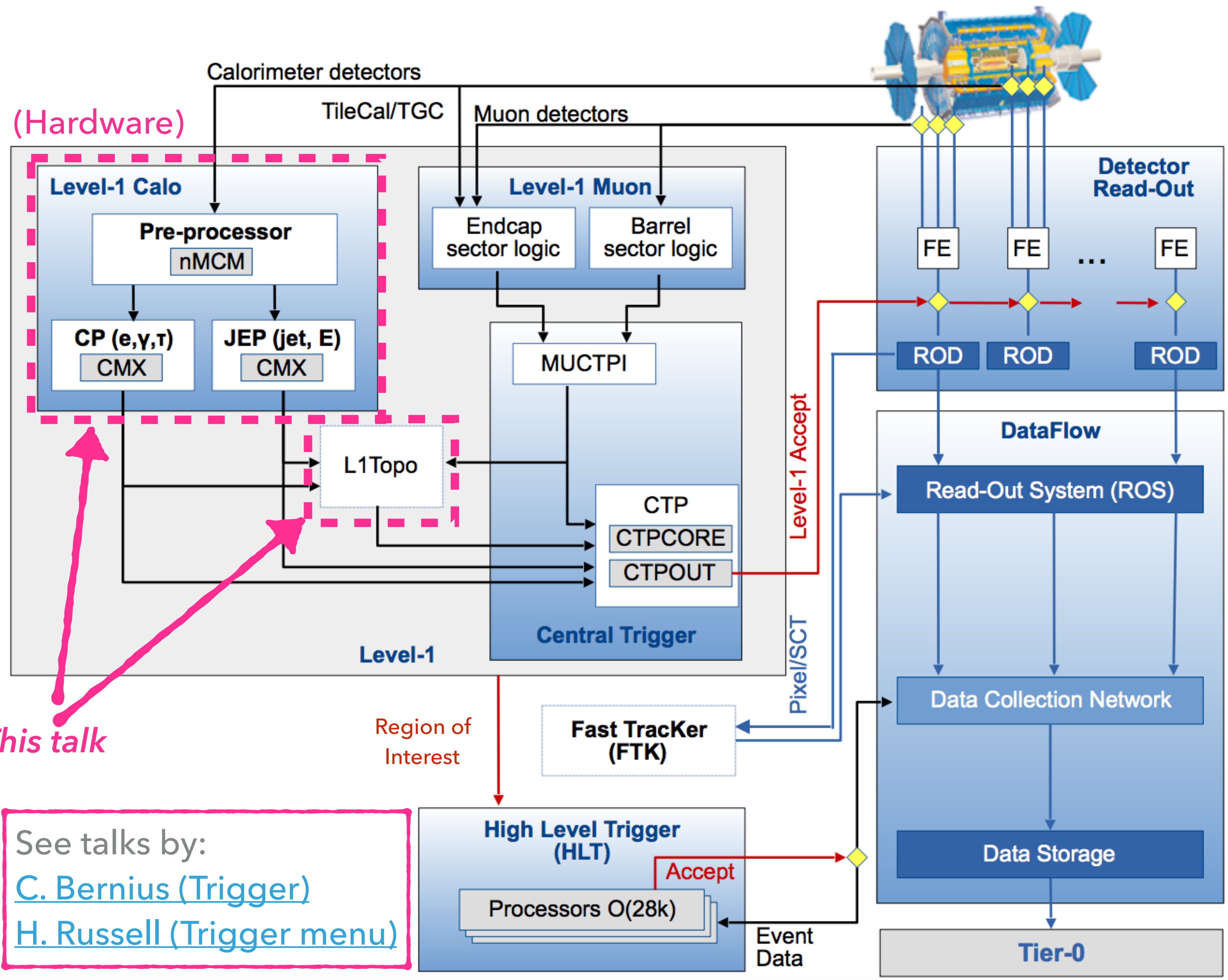




Luminosity public results

THE ATLAS TRIGGER SYSTEM

(Hardware)



This talk

(Software)

See talks by:
[C. Bernius (Trigger)]
[H. Russell (Trigger menu)]

DAQ public results

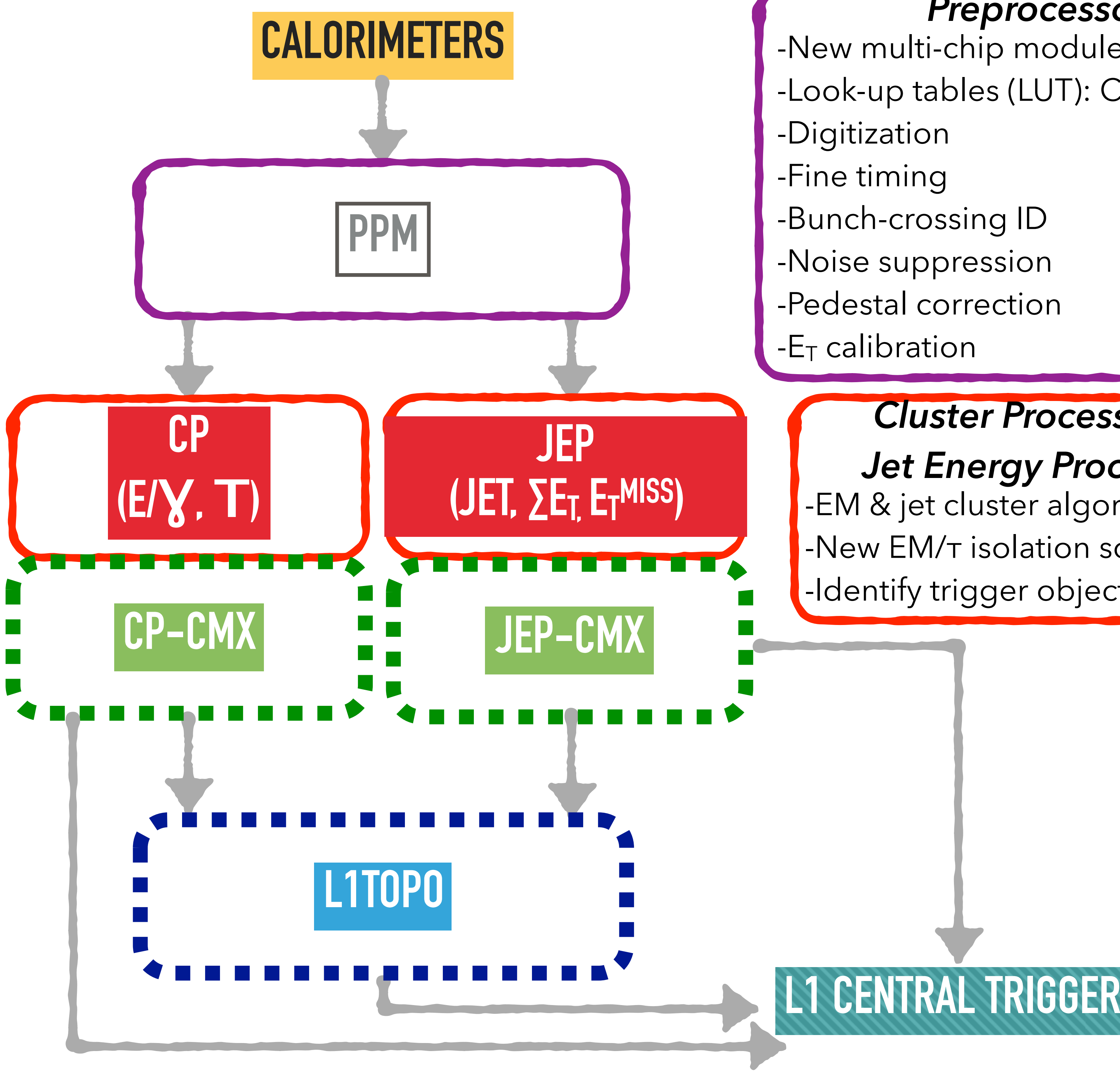
40 MHz

100 kHz

Detector readout limitation!

1 kHz
(~GB/s)

L1CALO TRIGGER IN RUN 2



Preprocessor

- -New multi-chip modules (nMCM)
- -Look-up tables (LUT): CP & JEP
- -Digitization
- -Fine timing
- -Bunch-crossing ID
- -Noise suppression
- -Pedestal correction
- -E_T calibration

Cluster Processor & Jet Energy Processor

- -EM & jet cluster algorithms
- -New EM/τ isolation scheme
- -Identify trigger objects (TOBs)

Extended Common Merger Modules

- -New for Run 2!
- -Extended η-dependent thresholding
- -Threshold multiplicities to CTP
- -TOBs to L1Topo

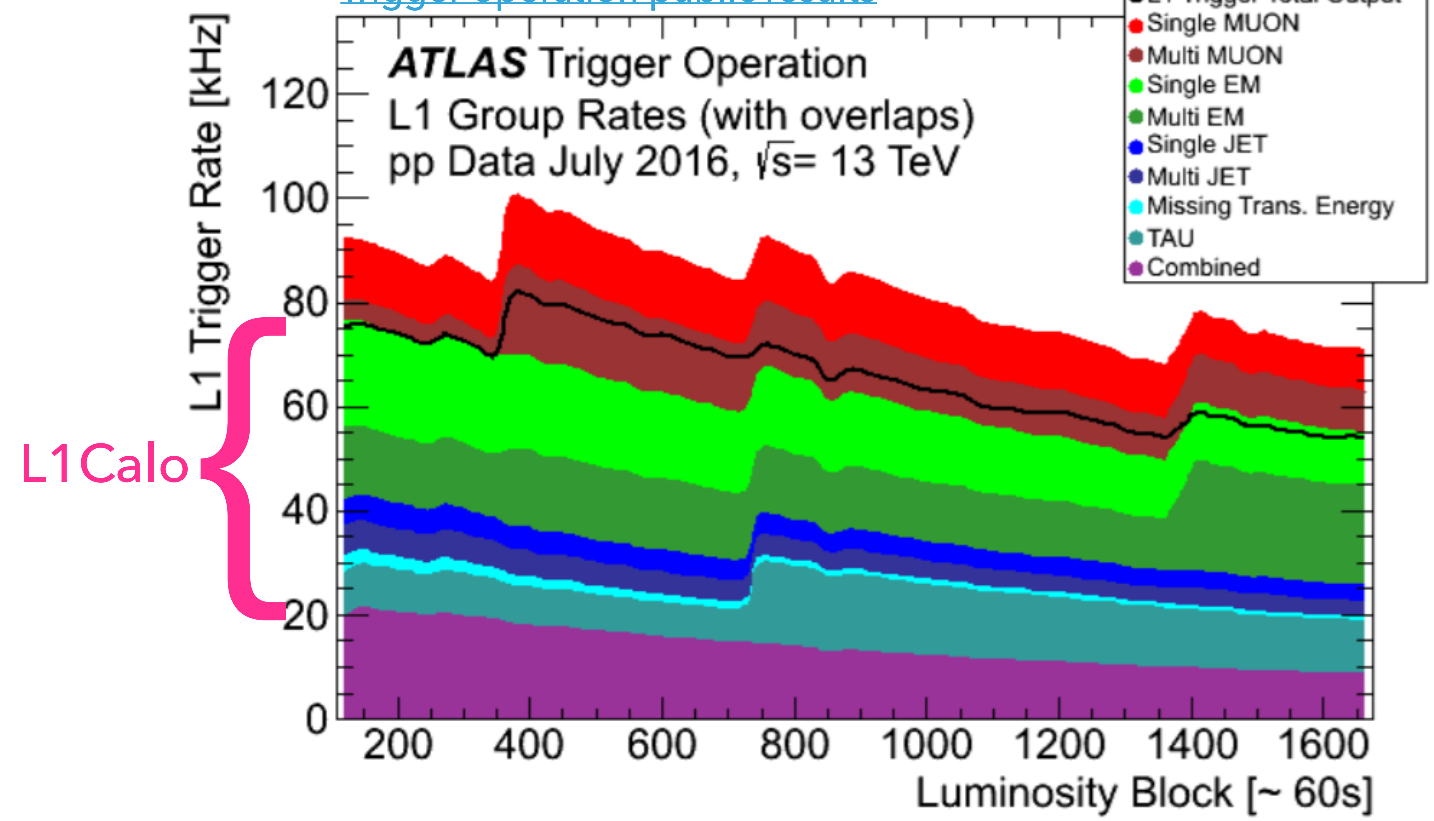
L1Topo

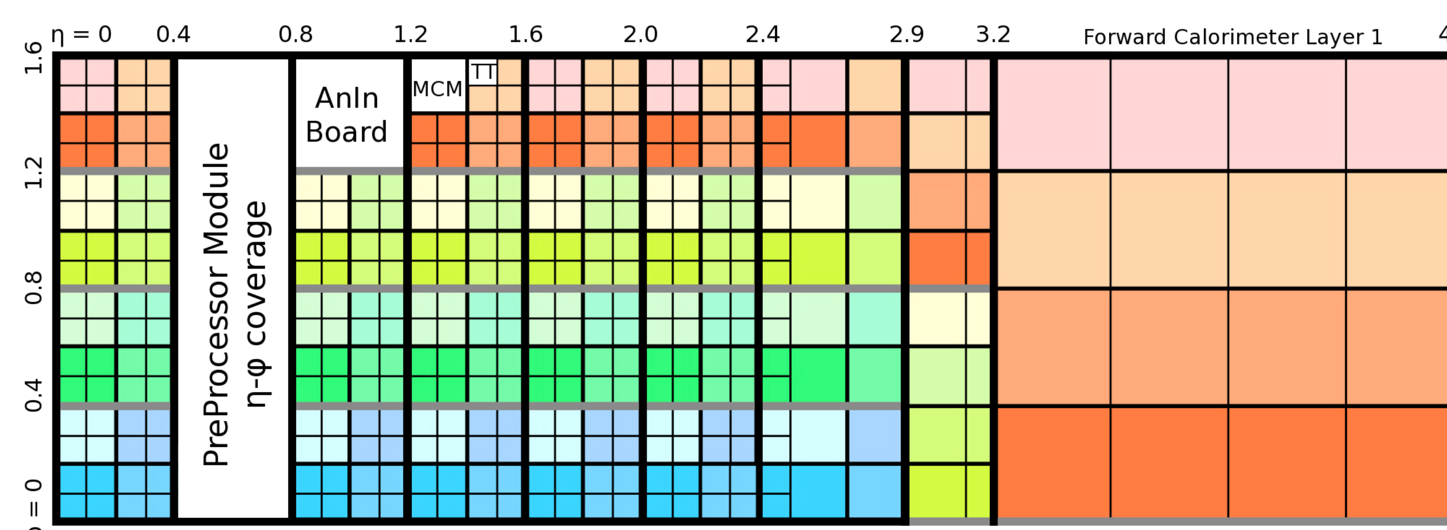
- -New for Run 2!
- -Topological selection using trigger objects (TOBs) from L1Calo & L1Muon

OBJECT SELECTION AND REGIONS OF INTEREST

- Local maxima determined using a sliding window algorithm
- Energy sums compared to a variety of η-dependent thresholds
  - ~2x as many as in Run 1
  - 16 EM, 16 tau, 25 jet, 16 sum E_T, 16 missing E_T, 8 missing E_T significance
- Regions of Interest (RoI) identified and sent to the high-level trigger
  - EM / tau: 2x2 trigger towers ($\Delta\eta \times \Delta\phi$ = 0.2 x 0.2)
  - Jets: 4x4 jet elements ($\Delta\eta \times \Delta\phi$ = 0.8 x 0.8)

Trigger operation public results

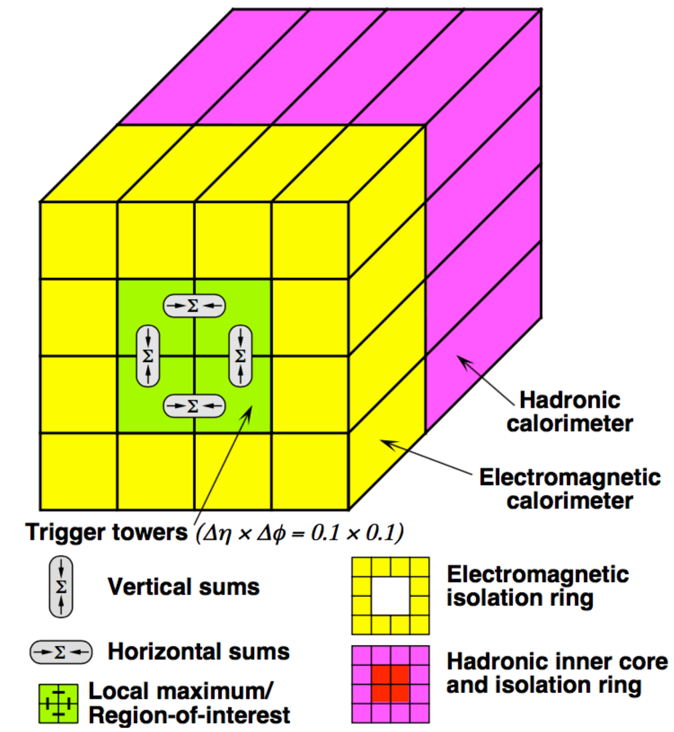




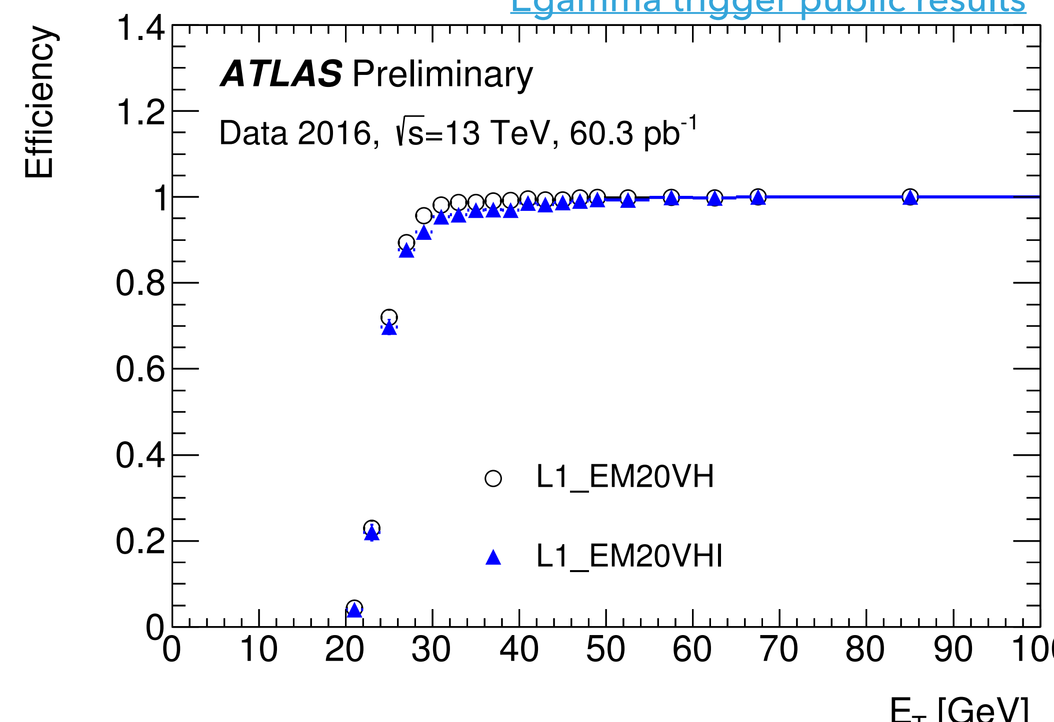
2012 JINST 7 P12008

EM ISOLATION

- Many interesting physics signatures involve isolated electrons or photons (e.g. Z→ee, H→γγ)
- Isolation selection: require energy in the vicinity of the EM cluster to be below a given threshold
  - EM: ring around local maximum
  - Hadronic: inner core behind local maximum
  - E_T- dependent thresholds with steps of 0.5 GeV
- Adding EM isolation requirement:
  - 45% rate reduction, only 2% efficiency loss for single electron trigger in 2016
- Retuned "medium" isolation thresholds for 2017 for additional improvements
  - 11% rate reduction, only 1% efficiency loss for L1_EM24VHIM!



Egamma trigger public results



Example: L1_EM20VHI

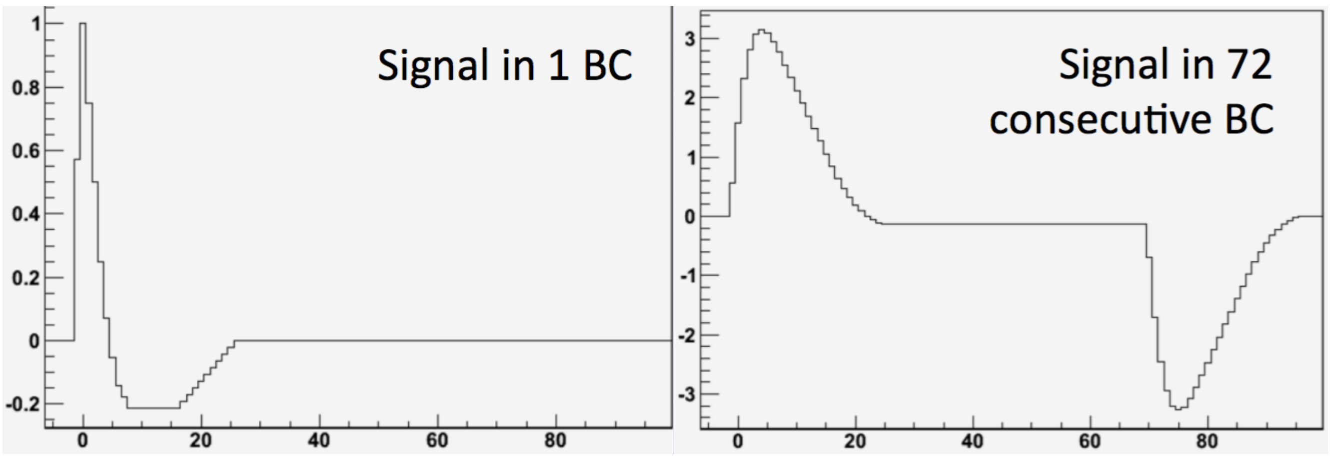
EM cluster with E_T > 20 GeV

Threshold varies with η

Hadronic core isolation

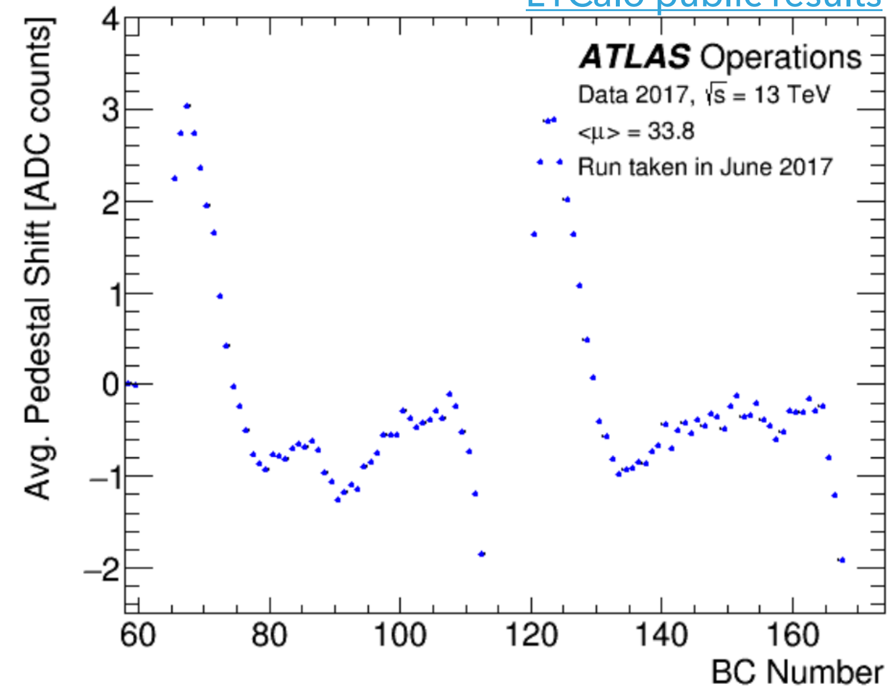
EM isolation

PPM IMPROVEMENTS: PEDESTAL CORRECTION

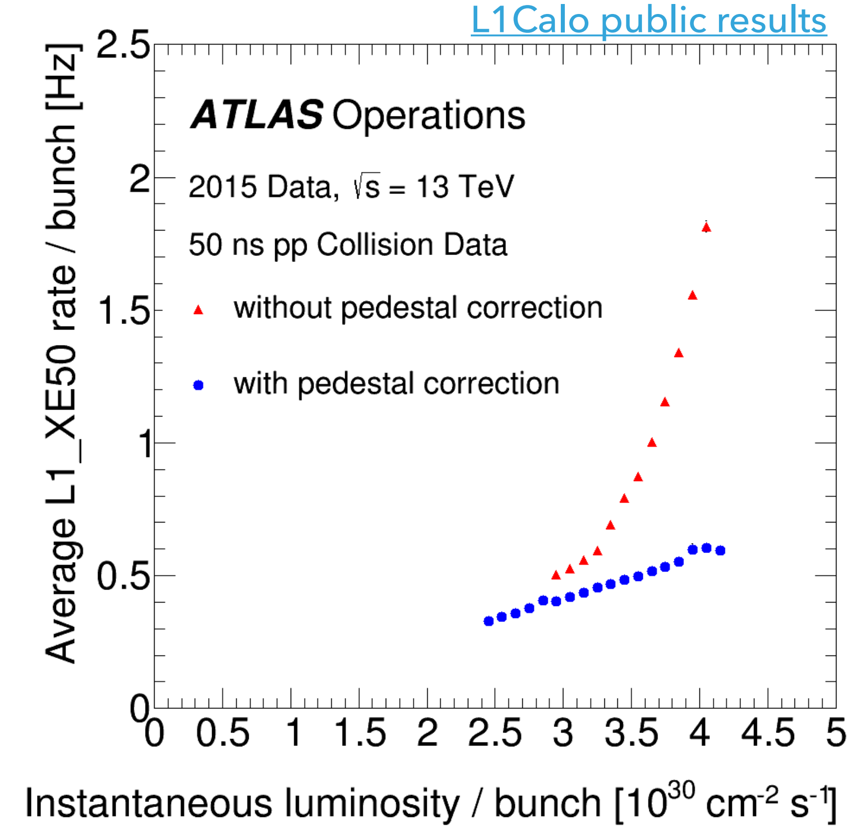


- Calorimeter pulses are longer than one bunch crossing
- Overlapping signals from adjacent bunch crossings cause baseline shift for L1Calo input signal
  - Increased rates at the beginning of the bunch train
  - Missing E_T trigger rates increase non-linearly with luminosity
- Improved preprocessor modules apply dynamic pedestal correction by calculating and subtracting the average input

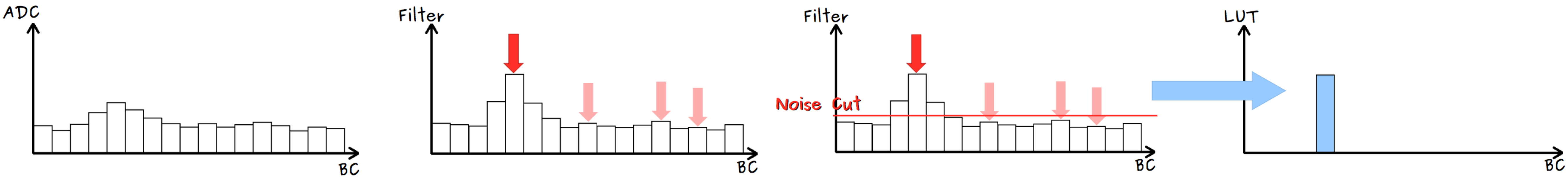
L1Calo public results



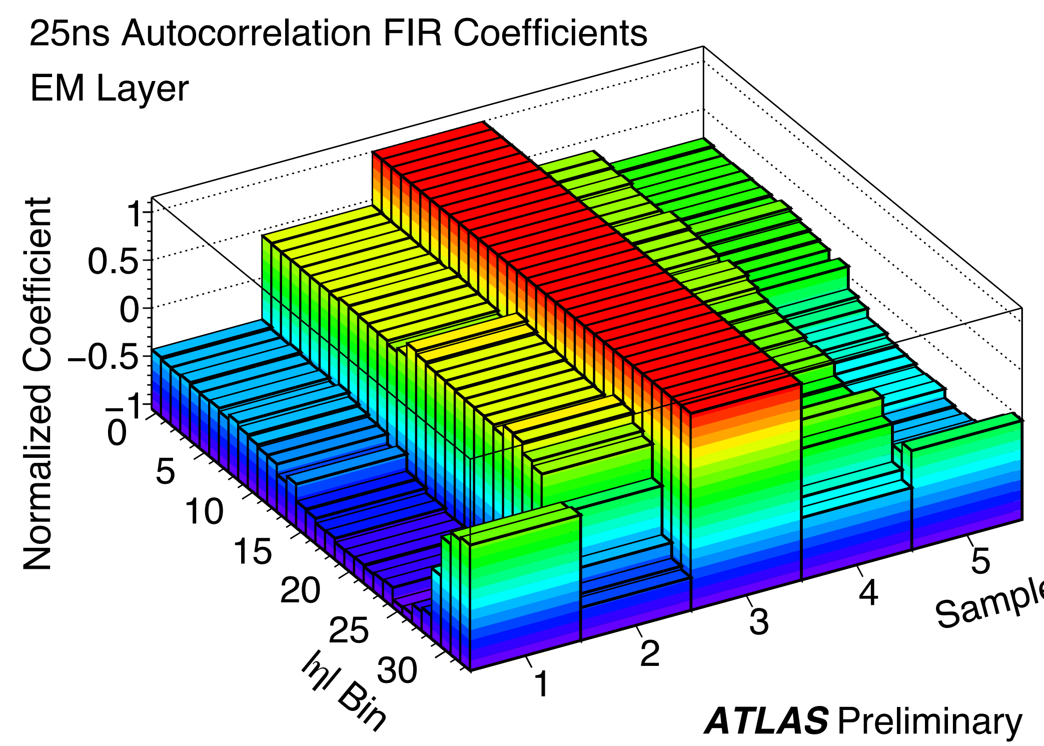
L1Calo public results



PPM IMPROVEMENTS: FILTERS & NOISE CUTS



- Reoptimized autocorrelation filters / noise cuts for improved high-pileup performance
  - Filter coefficients take into account correlations between bunch crossings
- Also reoptimized EM noise cuts for improved TE turn-on at low pileup (2016 p-Pb run)!



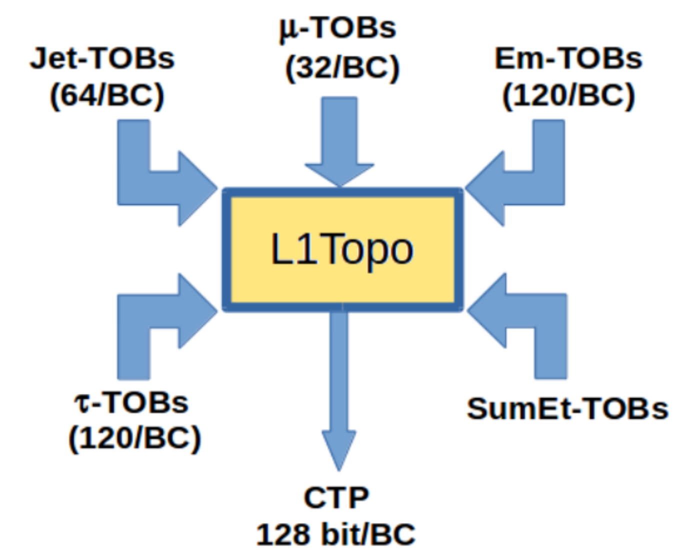
L1Calo public results

L1TOPO: NEW IN RUN 2!

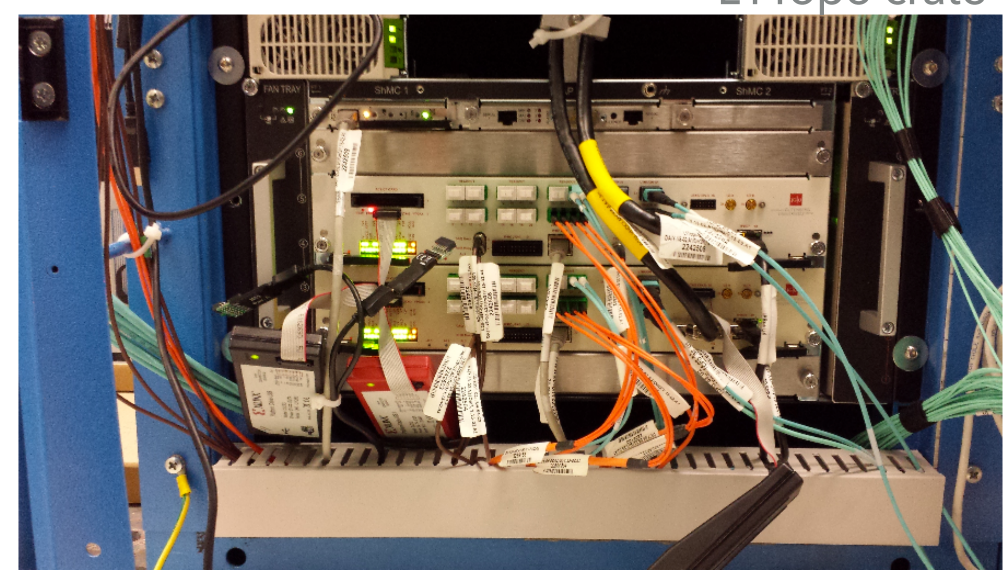
- How do we handle rate limitations as we exceed the LHC's design luminosity?
  - Prescale?
  - Raise thresholds?
- Traditional strategies risk throwing away interesting events
  - Particularly critical for new physics searches and studies of rare processes
- Instead, apply real-time kinematic and angular cuts at level-1
- Increase signal purity and reduce trigger rates without losing interesting physics

L1TOPO COMMISSIONING

- Can run up to 128 algorithms on four FPGAs in 75 ns (3 bunch crossings)
- Combines info from L1Calo and L1Muon trigger objects (TOBs)
  - Muons, electrons/photons, taus, jets, energy sums
  - (η, ϕ) coordinates, p_T, E_T, E_T^{miss}, isolation
- Installation/commissioning in 2015/2016
  - Algorithm validation: hardware/simulation comparisons
  - Test patterns in ATLAS with artificial "hot towers"
  - Validation of timing, readout stability at 100 kHz
  - Online/offline monitoring of timing, simulation/transmission
- First high-priority L1Topo trigger items enabled in Sept. 2016 (tau, B-physics)
- 2017: more items enabled, some of which are now primary triggers
- Commissioning of remaining algorithms continues



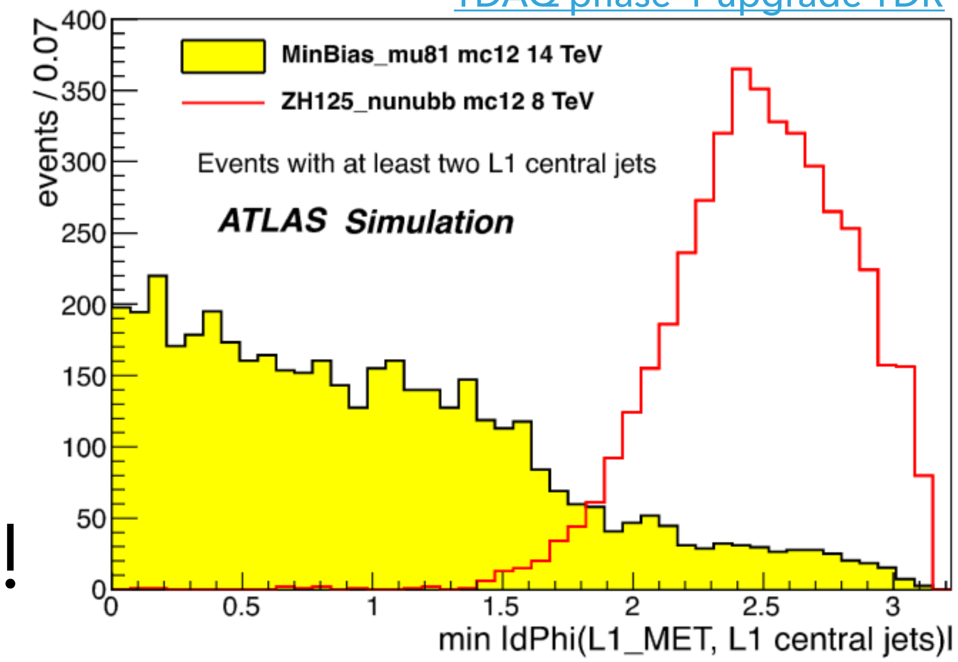
L1Topo crate



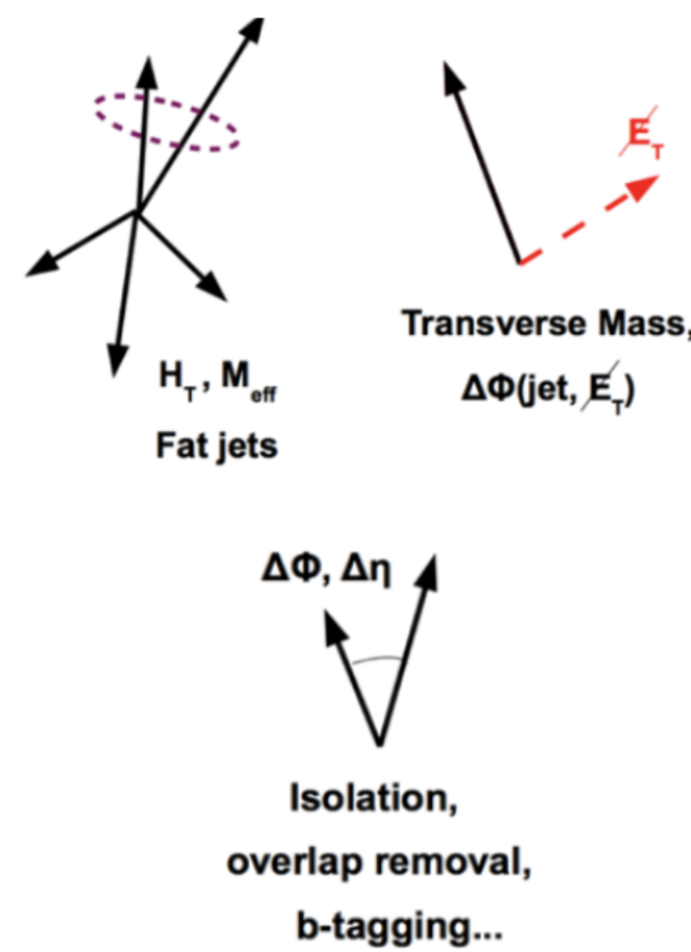
L1TOPO USE CASES

- L1Topo allows us to probe a wide range of physics signatures using a variety of algorithms
- The following is just a brief overview!

TDAQ phase-1 upgrade TDR



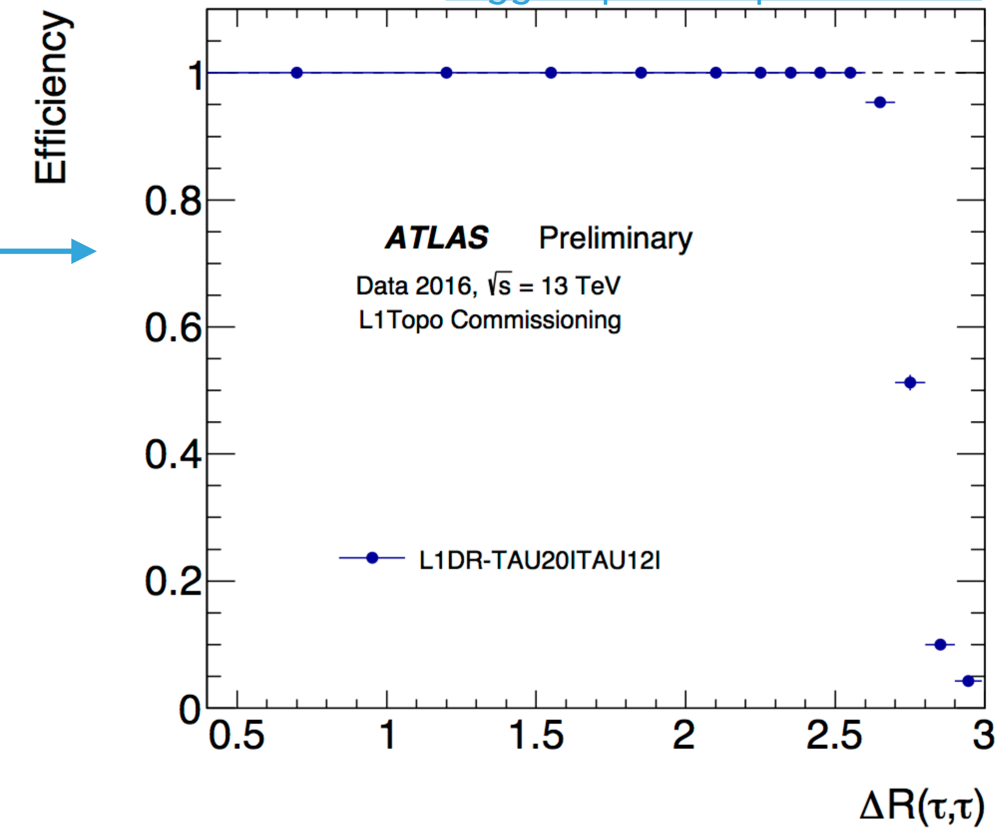
Physics signature	Input objects	Algorithms
H→ττ	τ, jets	Δη, Δϕ, ΔR, disambiguation
SUSY, ZH → νν bb	jets, E_T^{miss}	H_T, min Δϕ
B-physics	muons	ΔR, invariant mass
Long-lived particles	muons, E_T^{miss}	late muons (in next bunch crossing)
Lepton flavour violation	muons, EM clusters	ΔR



PHYSICS IMPACT

- SM Higgs →ττ trigger with ΔR(τ,τ) requirement is fully efficient in the signal region!
- B-physics dimuon trigger with ΔR(μ,μ) and invariant mass requirements reduces trigger rate by a factor of 4, with only 12% efficiency loss!

Trigger operation public results



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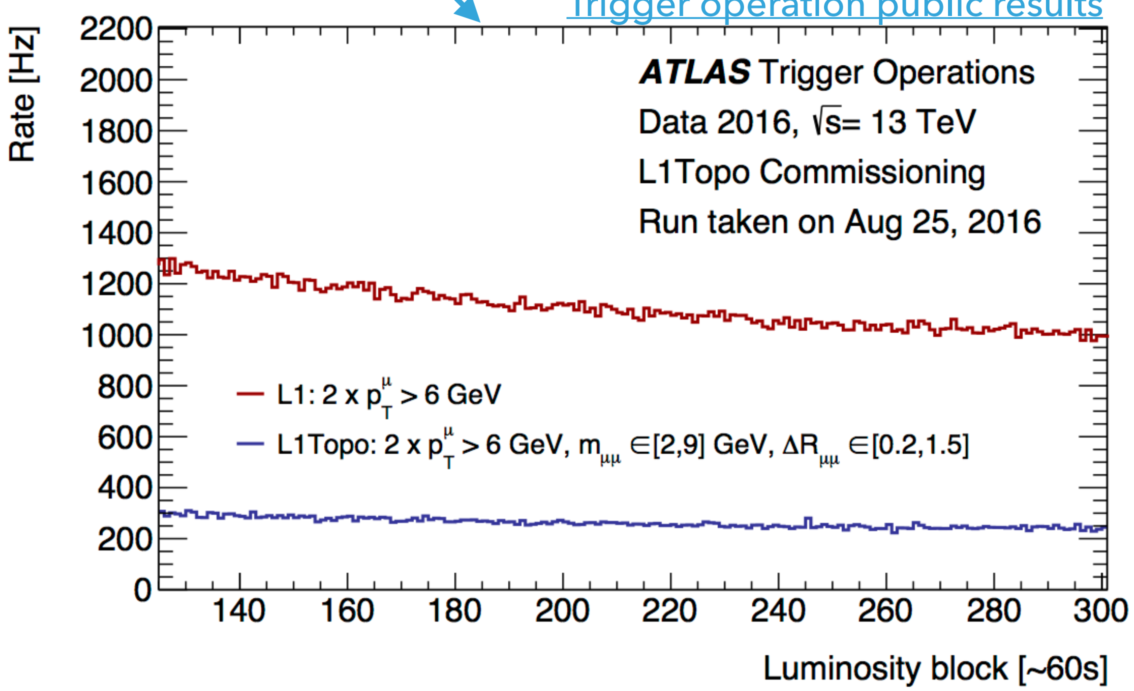

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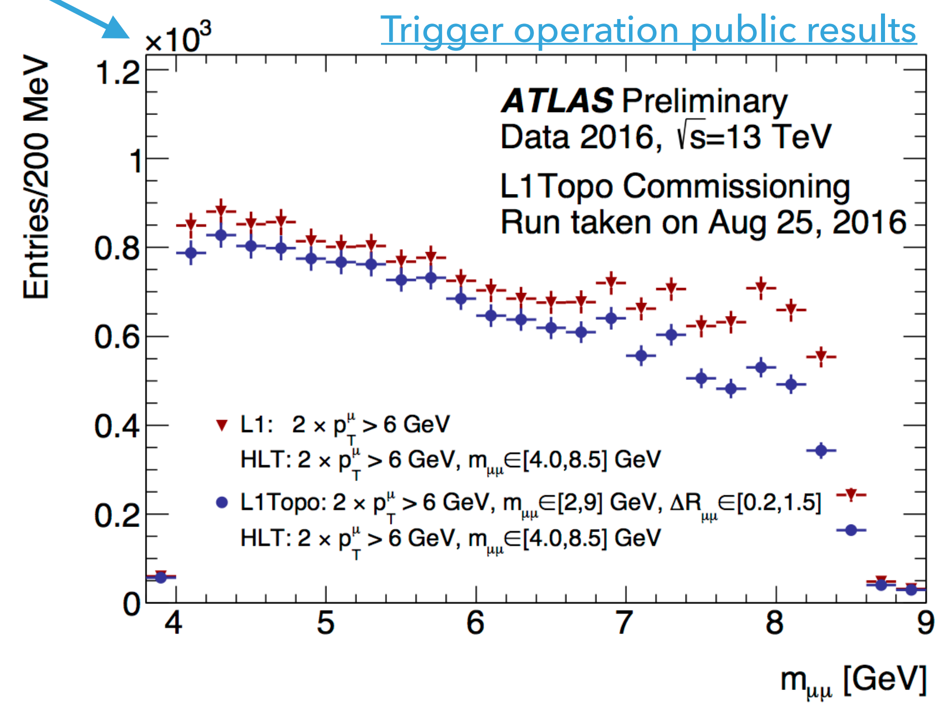

A MULTI-PRONGED APPROACH TO PILEUP MITIGATION IN RUN 2

- LHC conditions are becoming more challenging as we surpass the design luminosity!
- The L1Calo trigger employs a variety of strategies to mitigate the effects of increasing pileup on the rates and efficiency
- New for Run 2, the L1Topo trigger allows us to improve signal purity and reduce trigger rates while retaining interesting physics events